# Deriving the 12-lead Electrocardiogram From Four Standard Leads Based on the Frank Torso Model

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*Abstract* – **This paper proposes a lead method and a processing means for monitoring the 12-lead electrocardiogram (ECG) with four standard leads. Leads I, II of the M-L leads and leads V1, V6 of the chest leads are used to record the ECG signals. The ECG waveforms of leads V2 through V5 are derived from the input signals using the least squares method based on the Frank torso model. This method makes it possible to monitor the 12-lead ECG during ambulatory and long-term bedside monitoring. Examples recorded in the hospital environment show that the derived ECG waveforms can reproduce main features of the original signals, including the ST segment changes. The advantages of this method are discussed with compared to Dower's EASI ECG.**

***Keywords* – electrocardiogram, ECG, monitoring, lead, heart, model, cardiology**

## 1. INTRODUCTION

Myocardial ischemia and infarction are main targets in clinical monitoring. For correct diagnosis of these kinds cardiac disease, the 12-lead ECG is the standard. However, most current cardiac monitors do not provide the 12-lead ECG capacity because of many difficulties. Recording the 12-lead ECG needs ten electrodes; among these four are placed on the extremities of the patient. In clinical practice, mounting and maintaining such ten electrodes to record the 12-lead ECG are almost impractical for ambulatory monitoring. It is also very difficult to do this for long-term bedside monitoring, because the electrode amount and configuration severely restrict the mobility of the patient. Technically, most monitors use telemetry and at least eight channels of signal are necessary to be transmitted for the 12-lead ECG. This is not only expensive in cost, but also sometimes impossible because of the restriction of capacity in telecommunication.

To meet the need of monitoring 12-lead ECG, some recent studies have used directed 12-lead ECG with so-called EASI lead system [1]. The EASI lead system includes five electrodes: electrode E on the lower sternum, electrode A on the left axilla, electrode S on the upper sternum, electrode I on the right axilla, and an additional grounding electrode. The potential differences of A-I, E-S and A-S are recorded and the 12-lead ECG is calculated with coefficients developed by Dower [1]. Although the EASI 12-lead ECG has been evaluated by many clinical studies [2-4], there are some difficulties for it to be widely accepted by the clinical practice. An inherent limitation is due to the fact that the EASI 12-lead ECG is a calculated electrocardiogram, not directly recorded one. That means the EASI ECG only provides indirect, or secondary information. In clinical practice, most physicians generally do not trust secondary information for diagnosis. In addition, relevant laws in most counties prohibit using such estimated information for diagnostic behaviors.

In this paper, we propose an alternative method to monitoring 12-lead ECG from reduced number of electrodes. The idea arises from the fact that there is information redundancy in the standard 12-lead ECG. In most ECG machines, signals of eight leads (I, II, V1 through V6) are recorded. These signals are not completely independent. If a fixed dipole model is used to interpret the heart field, there are only three independent variables, so that it is possible to record ECG signals with part of the standard leads and derive ECG for other leads. In this way, the 12-lead ECG gives raw signals for the recording leads as main information and gives secondary information for other leads as reference in diagnosis. In the following sections, method and results are presented.

## 2. METHODS

### *2.1 The Electrode Configuration*

The electrode placement proposed in this study is shown in Fig. 1. The electrode positions of RA, LA, and LL are those used in exercise ECG proposed by Mason and Likor [5]. From these electrodes, ECGs of lead I, II are recorded and ECGs of lead III, aVR, aVL, and aVF are automatically obtained. Using the M-L limb leads is extremely important for ambulatory monitoring, because it avoids the interference from motion and reduces much disturbance of baseline and muscle noise. The electrodes of RA, LA, and LL also determine the Wilson terminal, based on which ECGs of leads V1 and V6 are recorded.

In addition to the above-mentioned five electrodes, a sixth electrode, RL, is used for grounding. This electrode configuration is aimed at two goals. First, it is sufficiently convenient and relatively comfortable for ambulatory or long-term bedside monitoring. Second, it provides as more information as possible in three spatial dimensions for

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**Abstract**

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deriving ECGs in leads V2 through V5.

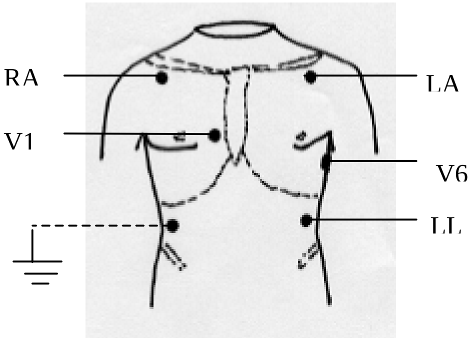

Fig. 1 The electrode placement

*2.2 The lead vectors and Frank image surface*

According to the fixed dipole model of the heart, the potential on a surface point can be described by

$$V = L^T \cdot H \qquad (1)$$

where L and H are column vectors with 3 elements, called lead vector and heart vector, respectively. The heart vector is the equivalent dipole source of the heart, which varies with time. The lead vector remains constant for a human subject, because the volume conductor of the torso is considered passive. Frank measured the values of the lead vector on the body surface with a typical human torso model, called image surface [6].

In our study, the Frank image surface is input into a computer with a digital scanner and the lead vectors for the modified leads I, II, and leads V1 thought V6 are precisely measured in terms of image processing software. Fig. 2 shows these leads positions on the image surface (the horizontal view).

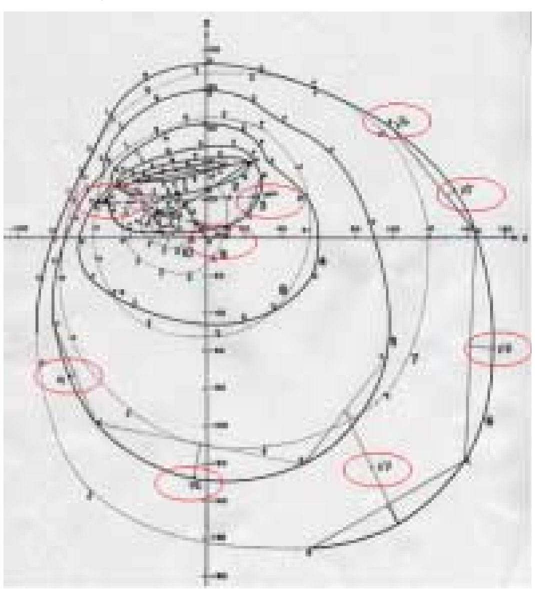
Fig. 2. The lead vector in the horizontal projection based on the Frank image surface

*2.3. The algorithm to derive 12-lead ECG*

Using the measured signals and the lead vectors of leads I, II, V1, and V6, the heart vector at a moment can be obtained by solving equation (1) with the least squares method that gives

$$H = (L_{mes}{}^T L_{mes})^{-1} L_{mes}{}^T V_{mes} \qquad (2)$$

Then, with *H* and values of the lead vectors of V2 through V5, values of V2 through V5 are derived using equation (1) again.

## 3. EXPERIMENTS AND RESULTS

In order to directly compare the derived ECG with the original signals, clinical ECG data were recorded in the hospital environment using the M-L electrode placement. The ECG data were recorded in to the memory card within an electrocardiograph (Nihon Kohden ECG9422). The data were then input into a computer and processed offline. A program based the above described algorithm calculated the values of V2 through V5 from leads I, II, V5, and V6. The derived ECG waveforms were compared with original data.

A typical example is shown in Fig. 3. On the left of the figure, the measured 12-lead ECG is shown. On the right, is the 12-lead ECG that would be shown on the monitoring display, where the four waveform of V2 though V5 are calculated from the measured ECG of lead I, II, V1 and V5. The accuracy of derivation in this case is very satisfactory. For example, the main features of this case are the ST segment depression and T wave abnormality (biphasic T wave in the chest leads). These features are reconstructed in the derived ECG with good precision. It is very clear that the derived ECG waveforms in V2 through V5 are useful in assisting diagnosis.

Another example is shown in Fig. 4. This ECG was obtained during a telemetry experiment. In the experiment, ECG was recorded in an ambulance with the engine running. The recorded ECG was transmitted through mobile internet to a remote computer. The computer then calculated the derived ECG. This experiment may not necessary for the evaluation of the algorithm. But we wanted to check if the proposed method was feasible in a practical environment of telemonitoring. As shown in Fig. 4, the main differences between the measured and derived waveforms are the magnitude of T wave in V2 and the QRS pattern in V3. Besides, the derived ECG keeps close to the original waveforms in general.

## DISCUSSION

In addition to arrhythmias, myocardial ischemia and infarction are main cases that need continuous monitoring in emergency centers or the ICU. For this purpose, the 12-lead ECG is necessary to be monitored in order to provide more information of ST segment changes and other ECG features for precise diagnosis. Unfortunately, the conventional 12-lead system is impractical for this purpose. Our proposal presented in this paper provides a way to realize continuous 12-lead ECG monitoring.

The electrode placement of our method has been proved to be convenient for ambulatory and long-term monitoring. Although our method uses one more lead than the EASI ECG, our method has advantages in the following aspects. First, we use a subset of the standard leads. The electrode positions are used to most medical professionals. As a result, the precise of electrode positioning will generally be good. Second and the most important is that our method keeps original ECG waveforms of eight leads as the first information, and provides four derived waveforms as the secondary information to improve the accuracy of diagnosis. This feature is a very important advantage as compared to the EASI ECG, where only secondary information is available.

As can be seen in the examples shown in Fig. 3 and 4, waveforms in the derived ECG are not exactly consistent to the originals. In fact, we cannot expect exact matching between the derived and the original waveform. Because in this study, the lead vectors are obtained from the image surface based on the Frank torso model. A single model cannot completely fit to all individuals in practice. The problem is in what extent the derivation errors are allowed for the clinical practice. To answer this problem, we are now quantitatively evaluating our data and developing some new algorithms to improve the derivation accuracy. Another problem that follows is in what way we use the derived ECG. At the moment, we think a practical way is to use the derived ECG in the sense of computer-add diagnosis. It is no doubtable that the 12-lead ECG constructed by eight measured leads and four derived leads contains more information than that used in current routine ECG monitors with a single or a few leads.

## CONCLUSION

We propose a lead method and a means to derive 12-lead ECG from reduced numbers of electrode for clinical monitoring. The electrode placement uses part of the standard leads and is convenient for ambulatory and long-term bedside monitoring. The algorithm for deriving 12-lead ECG has necessary degree of accuracy to monitor ST segment changes. Possible applications of this method are ambulatory monitor in emergency treatment, bedside monitoring, telemedicine and the Holter ECG.

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## REFERENCES

[1] G. E. Dower, “EASI-lead electrocardiography, Totemite Inc. Point Robeerts, WA, 1996.

[2] B. J. Drew, M. G. Adams, M. M. Petter, S. F. Wung, “ST segment monitoring with a derived 12-lead electrocardiogram is superior to routine cardiac care monitoring,” Am J Crit Care, Vol. 5(3): 198-206, 1996.

[3] B. J. Drew, M. G. Adams, M. M. Petter, S. F. Wung, “Comparison of Standard and derived 12-lead electrocardiograms for diagnosis of coronary angioplasty-induced myocardial ischemia,” Am J Cardiol, Vol. 79:639-644, 1997.

[4] B. J. Drew, M. M. Petter, S. F. Wung, M. G. Adams, C. Taylor, G. T. Evans Jr., and E. Fostor, “Acurracy of the EASI 12-lead electrocardiogram compared to the standard electrocardiogram for diagnosing multiple cardiac abnormalities,” J Electrocardiol, Vol. 32 Suppl 38-47, 1999.

[5] R. E. Mason and I. Likar, “A new system of multiple-lead exercise electrocardiography,” Am Heart J 71: 196-205, 1966.

[6] E. Frank, “The image surface of a homogeneous torso,” Am Heart J, 47: 757-768, 1954.

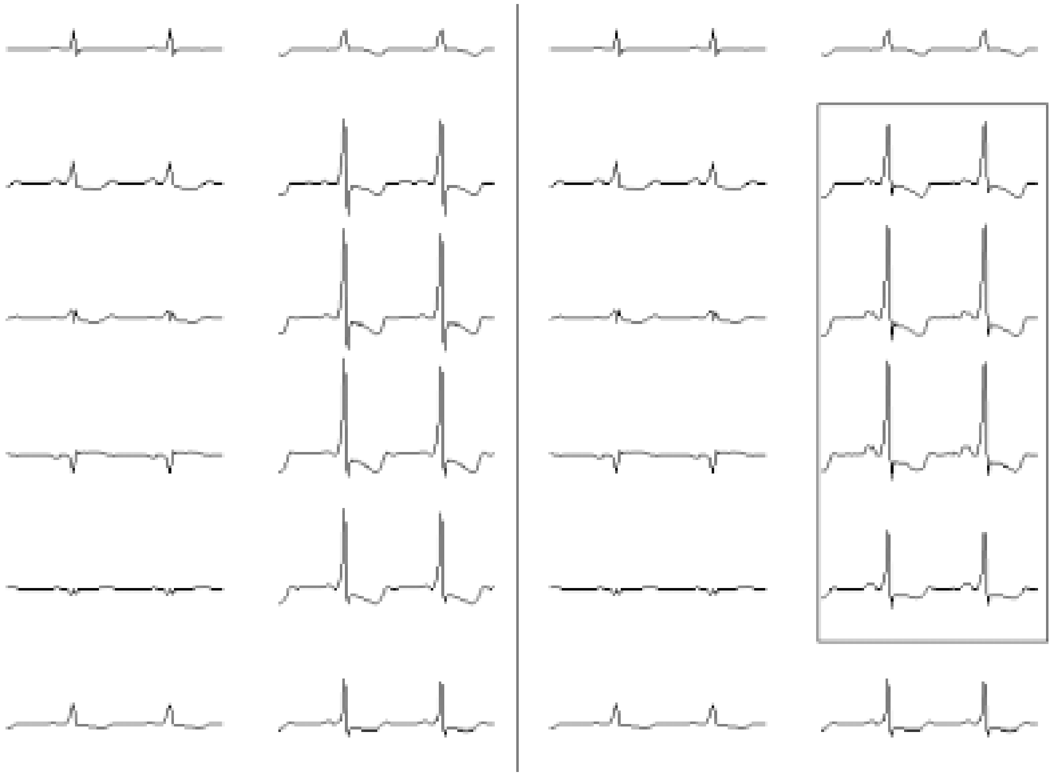

Fig. 3. An example of measured and derived ECGs. The left is the measured 12-lead ECG using the M-L leads. The waveforms in the box on the right are derived from I, II, V1 and V5 of measured ECG. In each figure, the waveforms on the left side are I, II, III, aVR, aVL, and aVF. On the right side, are V1 though V6.

Fig. 4. Another example of measured and derived ECGs. The left is the measured 12-lead ECG using the M-L leads. The waveforms in the box on the right are derived from I, II, V1 and V5 of measured ECG In each figure, the waveforms on the left side are I, II, III, aVR, aVL, and aVF. On the right side, are V1 though V6.